# APPLICATION OF MUSLE IN PREDICTION OF SEDIMENT YIELD IN IRANIAN CONDITIONS

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## Abstract
The Amameh catchment was selected to check the applicability of sediment estimation model for the agroclimatic conditions of Iran. The MUSLE was selected for application on this catchment. The efficiency of the model for sediment yield prediction was assessed. In the process, a constrained type of MUSLE was developed, which is more suitable than the original MUSLE for the study area. The new model was found to yield satisfactory results. The error of estimation and the average ratio between measured and estimated data for the developed constrained model was found to be –19.4 percent and 1.29, respectively.

Additional Keywords: MUSLT, USLE, Amameh catchment

## Introduction
Iran is facing a tremendous problem for identification of suitable models for estimation of soil erosion and sediment yield. To check the applicability of some of such types of models in Iran, selection of small catchments are required for which agroclimatic and hydrologic data are available. Historical data are available for the Amameh catchment and was thus selected for this study. Among the available soil erosion and sediment yield models, the USLE, MUSLE and their revised versions are some of the most commonly used models in the world. Evaluation of applicability of soil erosion models on a watershed is not easy. In contrast, sediment yield models are easier to apply because the data for these models can be measured at the watershed outlet.

Some previous researcher have reported that runoff is the best single indicator for sediment yield prediction (ASCE, 1969 and Williams, 1975), which has led to the development of Modified Universal Soil Loss Equation (MUSLE; Williams, 1975). The MUSLE has been used in different parts of the world along with different revisions (Asokan, 1981; Das, 1982; Nicks *et al.*, 1994; Banasik and Walling, 1996). In the present study, the MUSLE model has been applied on the Amameh catchment in Iran to test for its applicability. The predicted result of the model was compared with measured data of sediment yield with appropriate conversions wherever necessary.

## Material and methods
The Amameh catchment is located between 35°-51′-00″ and 35°-75′-00″ N latitude and 51°-32′-30″ to 51°-38′-30″ E longitudes. The entire catchment falls in the Tehran province. Runoff from the study area results from rainfall and snowfall. Some of the other geometric characteristics of the catchment are as listed in Table 1. The Amameh catchment is mainly covered by mountainous rangelands, comprising about 80% of area.

**Table 1. Some of the geometric factors of the Amameh catchment**

| | |
|---|---|
| **Area (ha)** | 3712 |
| **Mean elevation (m)** | 2620 |
| **The most top point elevation (m)** | 3868 |
| **Outlet elevation above sea level (m)** | 1800 |
| **Catchment perimeter (km)** | 29.5 |
| **Average slope (%)** | 28.5 |
| **Weighed average slope of main river (%)** | 14.7 |
| **Average slope of main river (%)** | 13.8 |
| **Length of the main river (km)** | 13.5 |

The annual mean depth of precipitation, calculated by the Thiessen method, was found to be 848.8 mm, which mostly falls during the winter and spring seasons (December to May). The annual mean temperature in the area is 8.6°C, whereas the absolute maximum and minimum temperatures are 35 and -24°C respectively. The annual average of evaporation is about 130 mm, whereas the lowest and the highest values of evaporation occur during the months of February and July, respectively (Sadeghi, 1993).

There were two hydrometery stations, which were located at the outlet (Kamarkhani) and the middle (Baghtangeh) of the catchment over the main stream. Both the stations were equipped with scale, limnograph (recorder) and bridge for the last 30 years. The stream discharge was measured by broad crested weirs and available relationships between stage and discharge. The average long-term discharge at the Kamakhani station was 0.575 $m^3s^{-1}$ (WRRO, Iran, 1996). The maximum and minimum of observed discharges were 21.2 and 0.01 $m^3s^{-1}$, respectively. April and September are the wettest and driest months, respectively, during the year. The average annual runoff is equal to 18.694 $Mm^3$ (503.610 mm), which is almost 59 percent of the yearly precipitation. The sediment concentration was sampled with the help of bottle samplers by using the depth integration method (WRRO, Iran, 1996). The average long-term discharge of the suspended load of sediment yield was around 5.47 t $day^{-1}$ or 0.537 t $ha^{-1}$ $year^{-1}$ that is about 106.63 mg $liter^{-1}$. Fifteen storms, for which an accurate and a reported data were available, were selected in the present study and the detailed information is shown in Table 2.

The MUSLE model (Williams,1975), which is a modified version of the USLE (Wischmeier and Smith, 1965), was applied on the catchment. A computer-oriented method of optimizing hydrologic model parameters (Decloursey and Snyder, 1969) had been used to determine a prediction equation (Williams, 1972). About 778 individual storm events in 18 catchments with areas ranging from 15 to 1500 ha were investigated. The equation that best fit the data was of the following form:

$$S=11.8(Q.q_p)^{0.56}\ K.LS.C.P \qquad (r = 92\%) \qquad (1)$$

where S is sediment yield in tonnes, Q is volume of runoff in $m^3$, $q_p$ is peak flow rate in $m^3s^{-1}$ and K, LS, C and P are respectively, the erodibility, topography, crop management and soil erosion control practice factors similar to the USLE model (Williams and Berndt, 1972).

**Table 2. Selected storms and their characteristics in Amameh watershed**

| No. | Storm Date | Depth (mm) | Max. $I_{30}$ (mm $h^{-1}$) | Duration (h) | Volume | | Peak flow ($m^3s^{-1}$) |
|---|---|---|---|---|---|---|---|
| | | | | | ($m^3$) | (mm) | |
| 1 | April 23,70 | 9.05 | 12.00 | 3.00 | 13680 | 0.369 | 0.857 |
| 2 | April 14,71 | 19.05 | 18.60 | 6.50 | 95580 | 2.575 | 8.552 |
| 3 | Aug. 2,72 | 7.50 | 11.60 | 2.00 | 11466 | 0.309 | 0.890 |
| 4 | Nov. 3,72 | 9.55 | 29.60 | 2.25 | 64350 | 1.734 | 3.400 |
| 5 | July 18,74 | 13.15 | 51.00 | 1.75 | 27540 | 0.742 | 4.000 |
| 6 | April 23,75 | 14.00 | 9.60 | 5.00 | 66600 | 1.794 | 6.800 |
| 7 | July 22,76 | 21.25 | 29.00 | 5.00 | 64440 | 1.736 | 10.440 |
| 8 | April 29,80 | 11.00 | 13.70 | 4.00 | 97065 | 2.615 | 4.148 |
| 9 | April 25,83 | 20.35 | 30.00 | 6.50 | 68634 | 1.849 | 3.432 |
| 10 | May 5,84 | 6.86 | 8.12 | 2.50 | 8712 | 0.235 | 1.381 |
| 11 | July 25,88 | 4.00 | 10.40 | 2.00 | 32040 | 0.863 | 2.149 |
| 12 | Nov. 18,88 | 9.50 | 35.00 | 4.00 | 16353 | 0.441 | 0.816 |
| 13 | Mar. 13,89 | 16.36 | 80.00 | 2.50 | 80064 | 2.157 | 1.800 |
| 14 | Oct. 28,90 | 11.38 | 52.00 | 1.50 | 7578 | 0.204 | 0.908 |
| 15 | April 6,97 | 9.20 | 9.60 | 7.25 | 35656 | 0.961 | 2.005 |

The values of 0.24, 18.18 and 0.66 were thus allotted to the catchment parameters of K, LS and P, respectively. The C value also changed from 0.150 to 0.202 according to the season in which the storm occurred.

**Results and Discussion**

The watershed parameters and runoff on the Amameh catchment were used in applying equation (1) and the results are presented in Table 3. The model significantly overestimated the sediment yield as compared with the measured values. The relationship between these two sets of data is shown in Figure 1. These lead to the conclusion that a suitable calibration can be made to obtain an accurate sediment yield prediction.

An attempt was then made to obtain the appropriate power quotient "m" as it is equal to 0.56 in Equation (1) for the MUSLE for the study area. To get this value, the model was applied with the measured sediment yield data and the other calculated characteristics of the watershed. Different types of relationships were evaluated to obtain the best fit. The results showed that the model obtained by applying the multiplication and the same power quotient (m) for volume (Q) and rate of runoff ($q_p$) gave the best fit. Then, the magnitudes of the power quotient were determined.

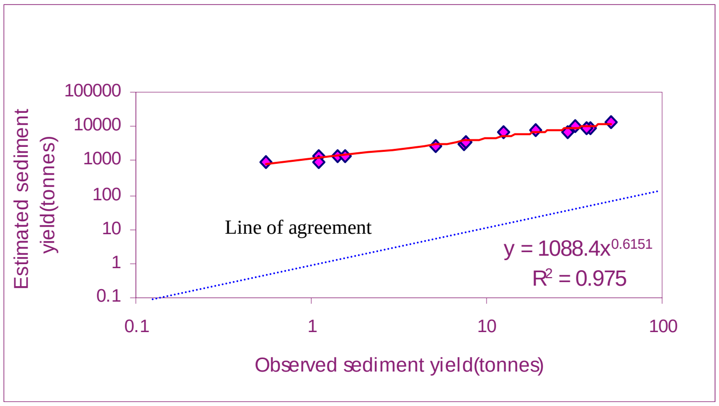


**Figure 1. Comparison of the observed and the computed sediment yield**

**Table 3. Estimated and the measured sediment yield**

| **Storm** | **Sediment yield (tonnes)** | |
|---|---|---|
| | **Measured** | **Estimated** |
| **April 23,70** | 1.419 | 1303.947 |
| **April 14,71** | 51.407 | 14045.780 |
| **Aug. 2,72** | 0.555 | 899.584 |
| **Nov. 3,72** | 12.380 | 6581.299 |
| **July 18,74** | 7.421 | 3221.938 |
| **April 23,75** | 31.742 | 10090.970 |
| **July 22,76** | 39.512 | 9414.720 |
| **April 29,80** | 36.742 | 9447.725 |
| **April 25,83** | 28.718 | 6997.629 |
| **May 5,84** | 1.575 | 1322.991 |
| **July 25,88** | 5.133 | 2626.928 |
| **Nov. 18,88** | 1.110 | 1374.223 |
| **Mar. 13,89** | 18.805 | 7919.086 |
| **Oct. 28,90** | 1.098 | 948.364 |
| **April 6,97** | 7.598 | 3588.906 |

The magnitude of quotient "m" was found to be very low, possibly due to a very low quantity of sediment yield from the watershed. The value of quotient "m" was found to be varying from –0.241 to 0.152 with a mean value of –0.0104 and a standard deviation of 0.142. The average values of the positive and the negative "m" were found to be 0.081 and –0.192 respectively. If the constant value of unit conversion factor of 11.8 was ignored in the Equation (1) for simplification, the value of "m" was found to range from 0.070 to 0.336 with an average of 0.213.

Since the MUSLE model for sediment yield has been recommended for application to large storms (Williams,1975), an assessment was required to classify the appropriate limit of the storms to determine the value of "m" for the study area. For this reason the value of "m" was regressed to the runoff factors. If Q and $q_p$ are the volume of direct runoff in $m^3$ and the peak discharge in $m^3s^{-1}$ respectively, the following equations can be established between the predictor and the criterion variables:

$$m = -0.1912 + 0.00004Q \qquad (r=0.890) \qquad (2)$$
$$m = -0.1368 + 0.037064q_p \qquad (r=0.776) \qquad (3)$$

The relationships between the volume and the peak flow rate of runoff and power "m" were obtained in a logarithmic form which showed an increase in their values of regression coefficients, r. The values of (r) along with the equations are shown following:

$$m = -1.5990 + 0.1486 \ln(Q) \qquad (r=0.942) \qquad (4)$$
$$m = -0.1477 + 0.1542 \ln(q_p) \qquad (r=0.924) \qquad (5)$$

With respect to the calculated regression coefficient for Equations (5) to (8) that the parameter Q played a more important role than the $q_p$ but both of them significantly correlated to the power "m" as shown in Table 6. However both of them had to be considered for the analysis. In some cases, it was observed that the volume of the runoff was high whereas the peak flow rate was not as high. Due to which, the value of "m" was being calculated as negative and vice versa. As per the analysis of applied storms, it was also found that in all of the cases with negative values of "m" the runoff volume was less than 16500 $m^3$, and in case of Equation (4) it was so when the volume of runoff was below 47119 $m^3$. At the same time, the value of "m" remained negative when the peak discharge was less than 1.4 $m^3s^{-1}$. The limit for the peak flow rate by using Equation (3) was found to be 2.6 $m^3s^{-1}$, which is almost two times greater than the measured rates. This showed that the evaluation of largeness of the storms couldn't be done by using one of the runoff parameters, only. To overcome these complexities, it was observed that multiple regression analysis might be helpful.

By using the concepts of least square method, the following multiple regression equation was obtained to find the appropriate value of “m” for the application of MUSLE (for sediment yield) in the study area:

$$m= -1.00539+0.08881 \ln(Q)+0.07821 \ln(q_p) \qquad (6)$$

On application of Equation (6) with a known value of one of the runoff variables, the critical limit for another one was determined. In the other words, at first, the magnitude of the flood was defined quantitatively and then the applicability of the MUSLE for sediment yield prediction was determined consequently. Therefore, the following equation was developed for the sediment yield prediction for large storms occur over the Amameh catchment.

$$S=11.8(Q.q_p)^{0.081}K.LS.C.P \qquad (7)$$

Subject to:

$$0.08833 \ln(Q)+0.07786 \ln(qp)\geq 1$$

In spite of fewer measurements of the sediment concentration during the large storms, the performance of the developed model for estimation of sediment yield within the studied range of runoff volume and peak was good. The results of some other storms were used for verification of the model. The average error of the estimation after eliminating those storms, which were not satisfying the constraint of Equation (7) was found to be -19.40 percent, and the mean ratio of observed sediment to estimated one was 1.29.

## Conclusion

It has been found that runoff is a better indicator than rainfall for sediment prediction for the agroclimatic condition of Iran, also. This has been proved through a case study, which was carried out in the Amameh catchment of Iran. The available sediment yield models, which were developed under specific geographical conditions, need to be calibrated before application on this area. To reduce error in the analysis, sufficient number of the storms occurring during the different conditions with a wide range of variation should be considered for calibration and development of new equations. A constrained form of the MUSLE model has been developed for the prediction of sediment yield from the Amameh catchment which has given satisfactory results.

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